DOE's Effort to Improve Heavy Vehicle Fuel Efficiency through Improved Aerodynamics

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Kambiz Salari

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- Army 7’x10’ wind tunnel located at NASA Ames – Aeroflightdynamics Directorate (AMRDEC)
  - Nili Gold
- AEDC's National Full-Scale Aerodynamics Complex – 80’x120’ wind tunnel located at NASA Ames
  - Scott Waltermire, Joseph Sacco and Christopher Nykamp

Obtained comprehensive wind tunnel aerodynamic performance data for vehicle platoons

Army 7'x10' wind tunnel facility located at NASA Ames Research Center

Conducted full-scale wind tunnel tests in collaboration with Navistar to validate the aerodynamic performance of their SuperTruck 1 geometry

National Full-Scale Aerodynamics Complex (NFAC) located at NASA Ames Research

Overview

Timeline

Improve aerodynamic performance of heavy vehicles

- Obtained comprehensive performance data for aerodynamic benefits of heavy vehicle platoons
- In support of SuperTruck I program performed full-scale wind tunnel tests in collaboration with Navistar
- Designed the state-of-the-art integrated tractor-trailer geometry called Generic Speed Form (GSF1 and GSF2)

Budget

- Funding for FY16, $1000K
- Funding for FY17, $850K

Barriers

- Reduce aerodynamic drag of class 8 tractor-trailers by approximately 25% leading to a 10-15% increase in fuel efficiency at 65 mph

Partners

- Navistar, Inc.
- Kentucky Trailer and Wabash National
- Freight Wing Inc. and ATDynamics
- Frito-Lay, Spirit, and Safeway
- Michelin
- Praxair
- NREL
- NASA, Army, and Air Force

Class 7-8 tractor-trailers are responsible for 11% of the total US consumption of petroleum

2.5 million combination trucks[1]
66,161 average miles/year/vehicle
5.8 average miles/gallon

Aerodynamic drag reduction contribution

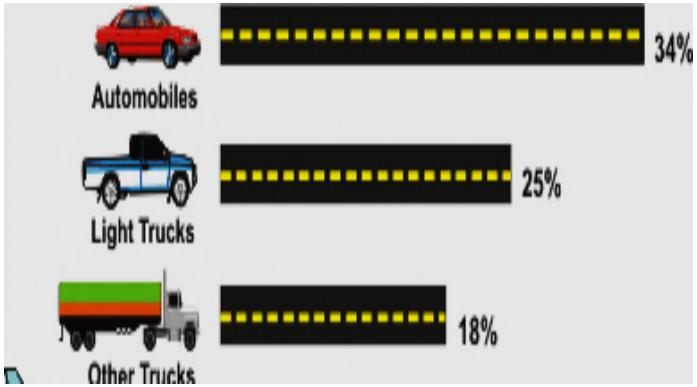
15% reduction in fuel use = 4.2 billion gallons of diesel fuel saved per year and 42 million tons of CO2 emission

$8.9 billion saved/year ($2.11 per gallon diesel)

Tractor-Trailer integration (GSF) radically decreases aerodynamic drag

Up to 40% reduction in fuel use

Wide-base single tires add about 4-5% to overall vehicle fuel economy



1. U.S. Department of Energy, Transportation Energy Data Book, Edition 35, October 2016

Tanker trailers are responsible for 1.3% of the total US consumption of petroleum

Approximately 200,000 tanker trailers[1]
60,000 average miles/year/vehicle
4.5 average miles/gallon

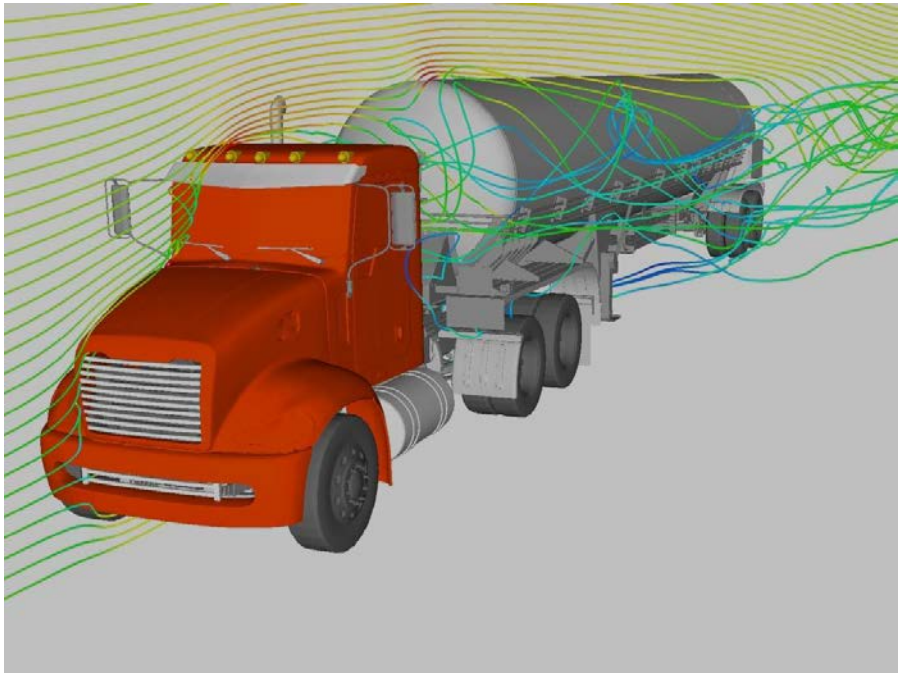
Aerodynamic drag reduction contribution

17% reduction in fuel use = 0.6 billion gallons of diesel fuel saved per year and 6 million tons of CO2 emission
$1.3 billion saved/year ($2.11 per gallon diesel)

Tractor-Trailer integration radically decreases aerodynamic drag

Up to 40% reduction in fuel use

Wide-base single tires add about 4-5% to overall vehicle fuel economy



1. National Tank Truck Association, www.tanktruck.org

Objectives

- **In support of DOE's mission,** provide guidance to industry to improve the fuel efficiency of class 8 tractor-trailers and tankers through enhanced aerodynamics
- **Demonstrate** new state-of-the-art aerodynamic body shapes, drag-reduction techniques, and concepts
  — Class 8 tractor-trailers and tankers
- **Develop the next generation of highly aerodynamic and integrated class 8 tractor-trailers and tankers**
- **Investigate the fuel economy benefits of truck platooning**
- **Joined with industry in promoting the new body shapes and getting aerodynamic devices on the road**
- **On behalf of DOE** to expand and coordinate industry participation to achieve significant on-the-road fuel economy improvement

Milestones

FY16

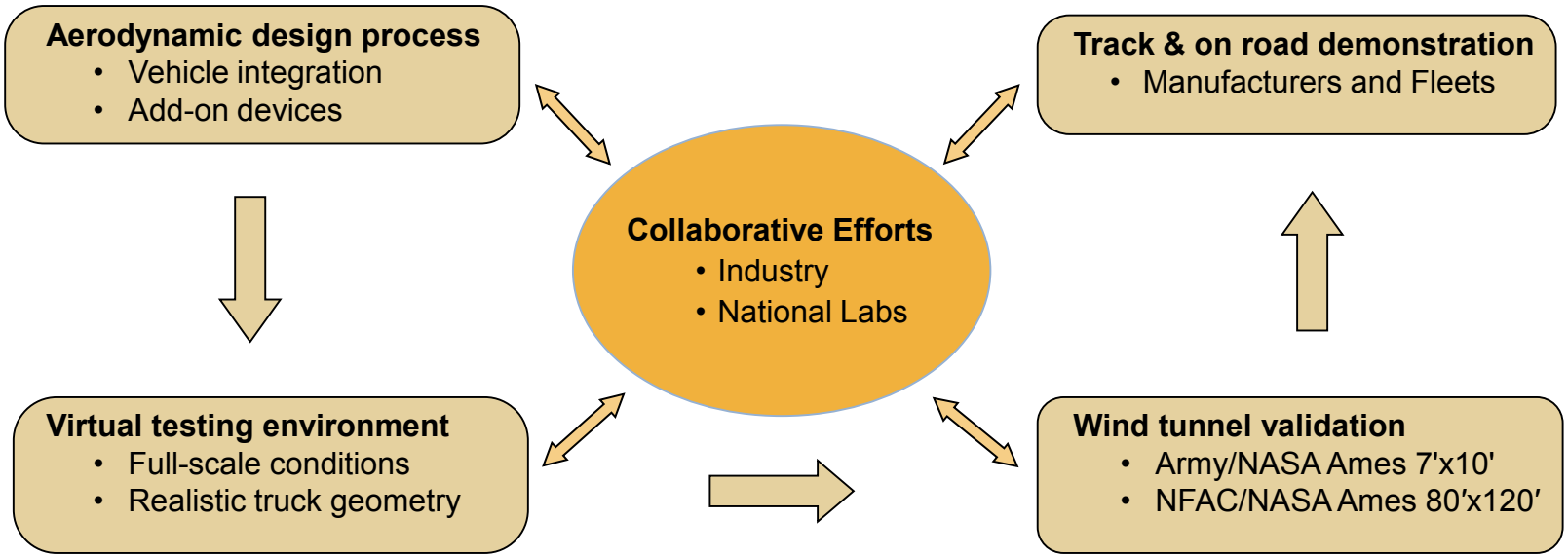
- **Designed the second-generation of our Generic Speed Form (GSF2)**
- Analyzed wind tunnel test results for GSF2
- Analyzed wind tunnel test results on aerodynamically treated tanker-trailers
- Performed wind tunnel tests to validate the performance of aero devices and integrated design for tractor-trailers and tankers

FY17

- **Performed scaled wind tunnel tests to obtain fuel economy benefits of truck platooning for single, two, and three vehicle configurations**
- **Analyzed wind tunnel test results for platooning to uncover the underlying physics responsible for the aerodynamic benefits**
- **Working closely with NREL to perform full-scale track tests of vehicle platoons for validation of the scaled wind tunnel tests**
- **Conducted full-scale wind tunnel tests at NFAC facility in collaboration with Navistar in support of SuperTruck I program**
- Investigated the performance of aero devices and integrated design for tractor-trailers and tankers

Science-based approach is used to develop an integrated highly aerodynamic heavy vehicles

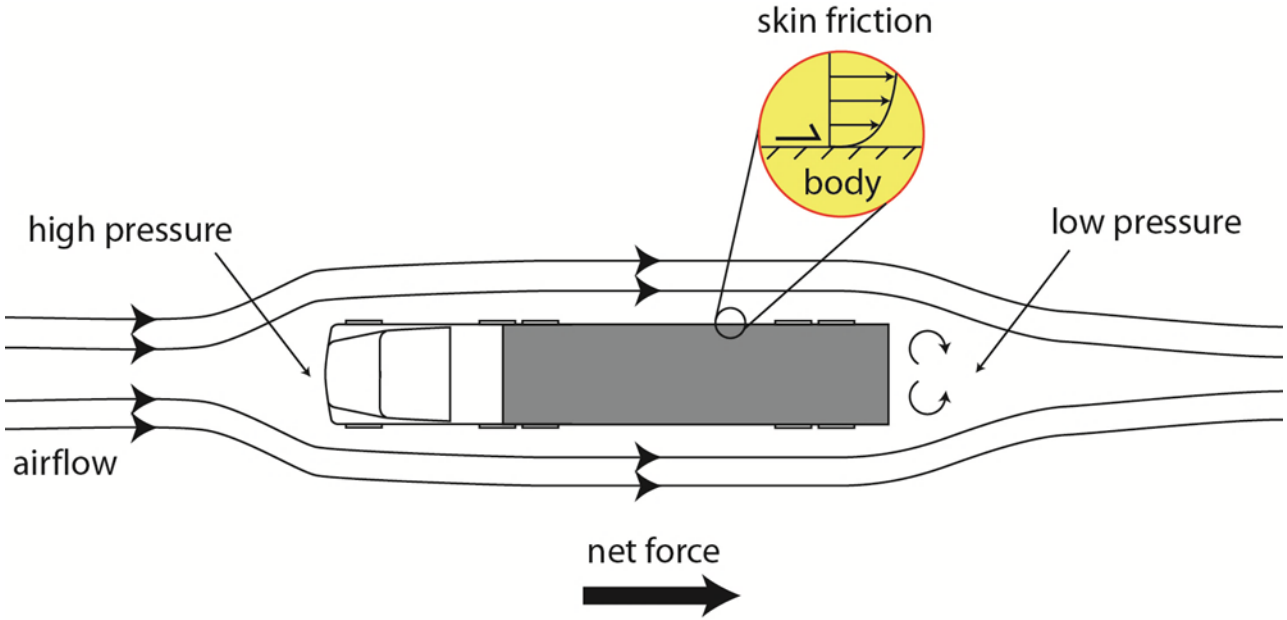
Validate aerodynamic body shapes and concepts with industry collaboration and feedback



Technical accomplishments

- **Designed the second generation** of an integrated tractor-trailer geometry from ground up that radically decreases aerodynamic drag and improves the fuel economy (GSF2).
  - GSF2 tractor design was completed with the aid of wind tunnel testing
  - GSF2 represents a breakthrough in aerodynamic performance
- **Conducted scaled experiments** at the Army 7'x10' wind tunnel facility at Ames Research Center to investigate the aerodynamic benefits of platooning
  - Single, two, and three vehicle configurations
- **Evaluated the aerodynamic performance** of integrated skirt and tail devices on vehicle platoons
- **Conducted full-scale wind tunnel tests at NFAC facility in collaboration with Navistar in support of SuperTruck I program**
- **Achieved international recognition** through open documentation and conferences

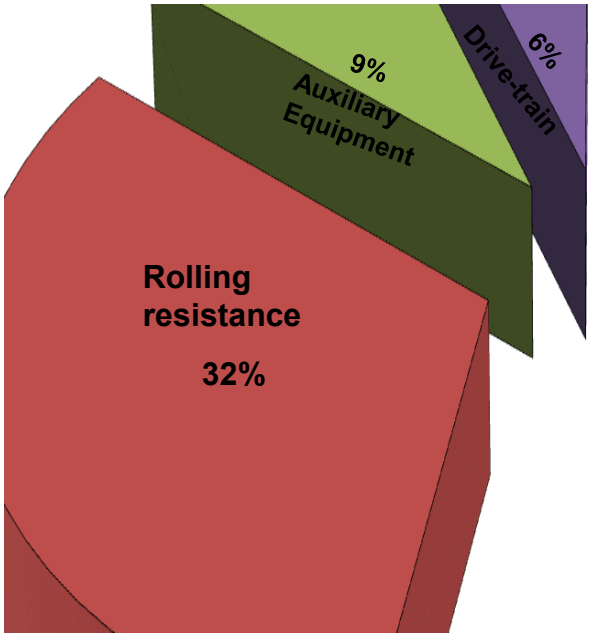
Improved fuel economy is achieved through enhanced aerodynamics

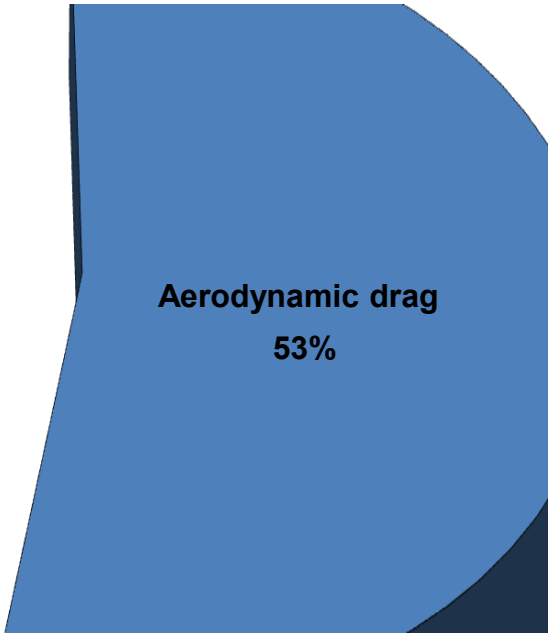


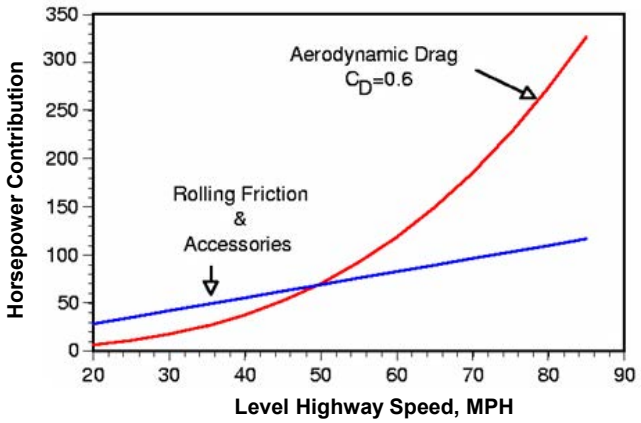
$$Drag = C_D \times S \times (1/2)\rho U^2$$

Shape **cross-section** **speed**

Heavy trucks use most of their usable propulsion energy to overcome drag and rolling resistance at highway speed





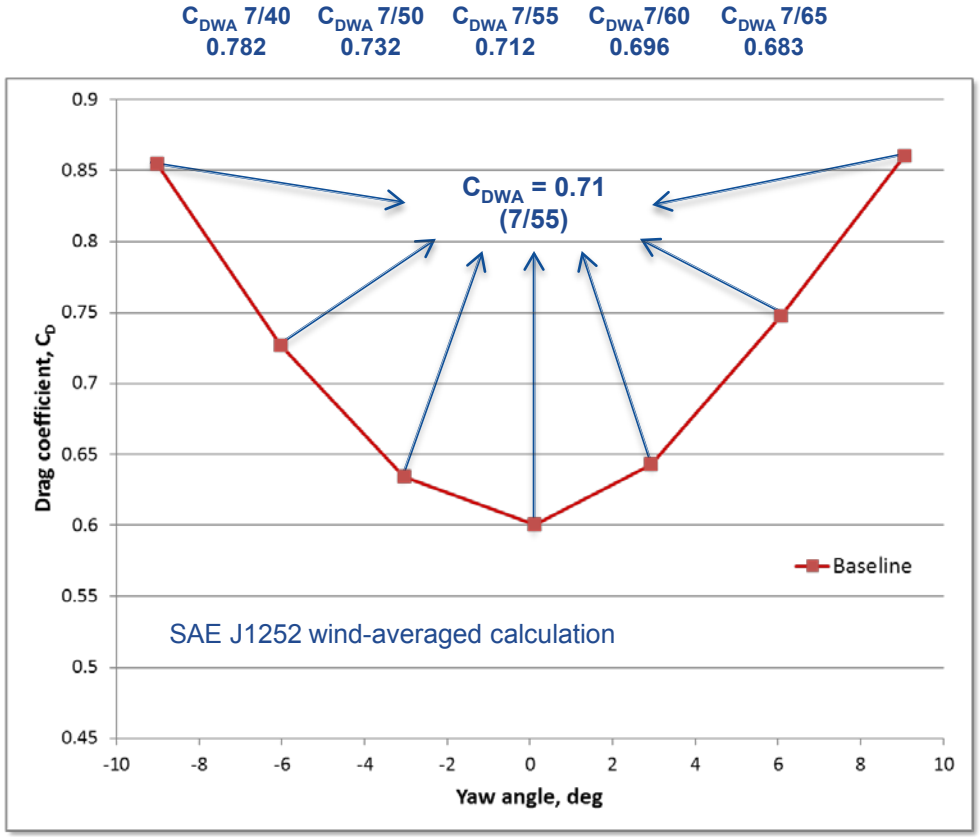


Wide-base single tires

Losses in nearly all of these categories can be reduced by employing presently available technology

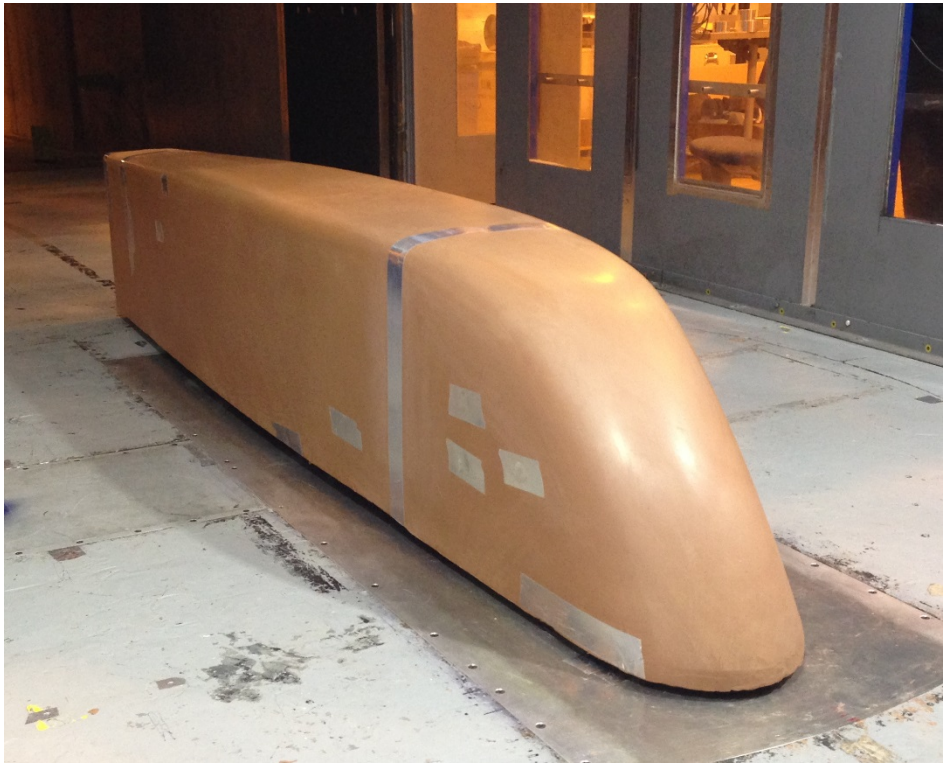
How to represent an aerodynamic performance of a typical vehicle on the road

Baseline geometry



Drag = 93% pressure + 7% skin friction

LLNL Generic Speed Form (GSF) geometries represent a breakthrough in heavy vehicle aerodynamics

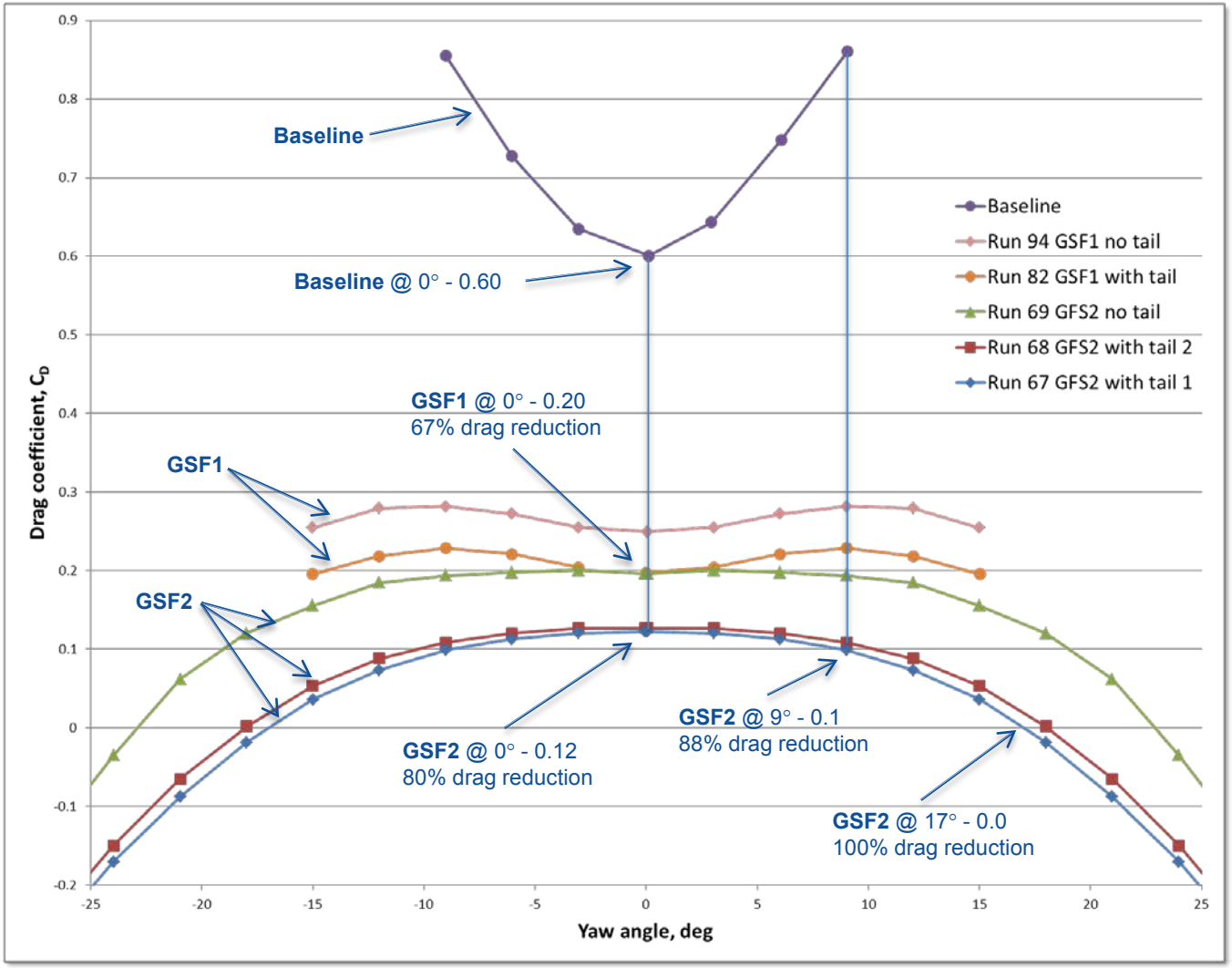


Generic Speed Form 2

Generic Speed Form 1

About 40% of the total drag is due to skin friction

GSF2 demonstrates radical drag reduction



We are working closely with NREL to investigate the fuel economy benefits of truck platooning

Vehicle platooning has shown aerodynamic benefits beyond what was expected

Body axis wind averaged drag measurements

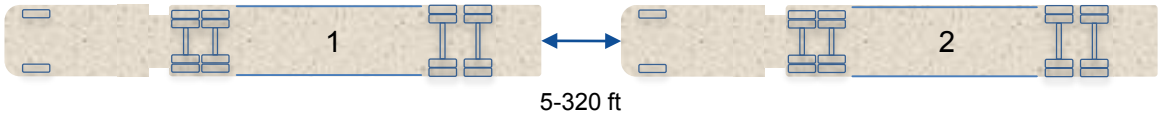
Army 7'x10' wind tunnel facility at NASA Ames Research Center

Vehicle platooning: configurations with skirt and boattail

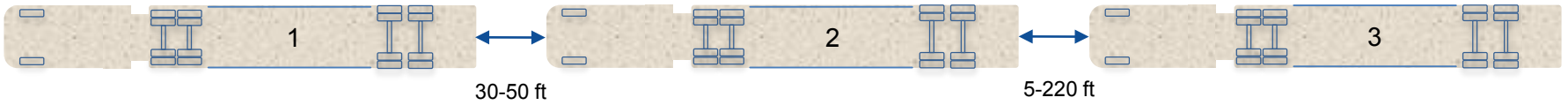
Aligned – single vehicle

Baseline geometry includes skirts

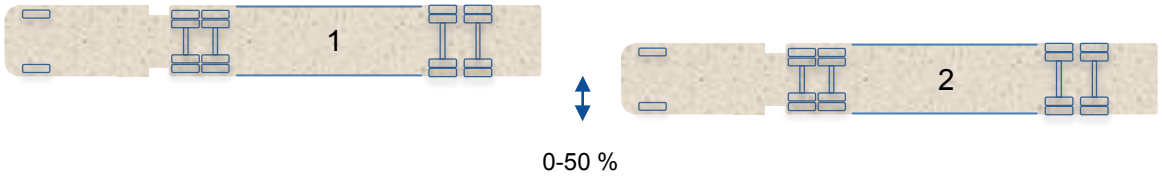
Aligned – two vehicles



Aligned – three vehicles

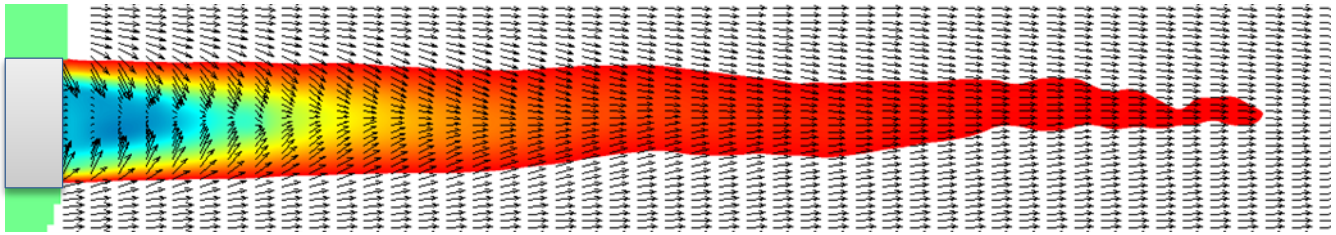


Misaligned – two vehicles



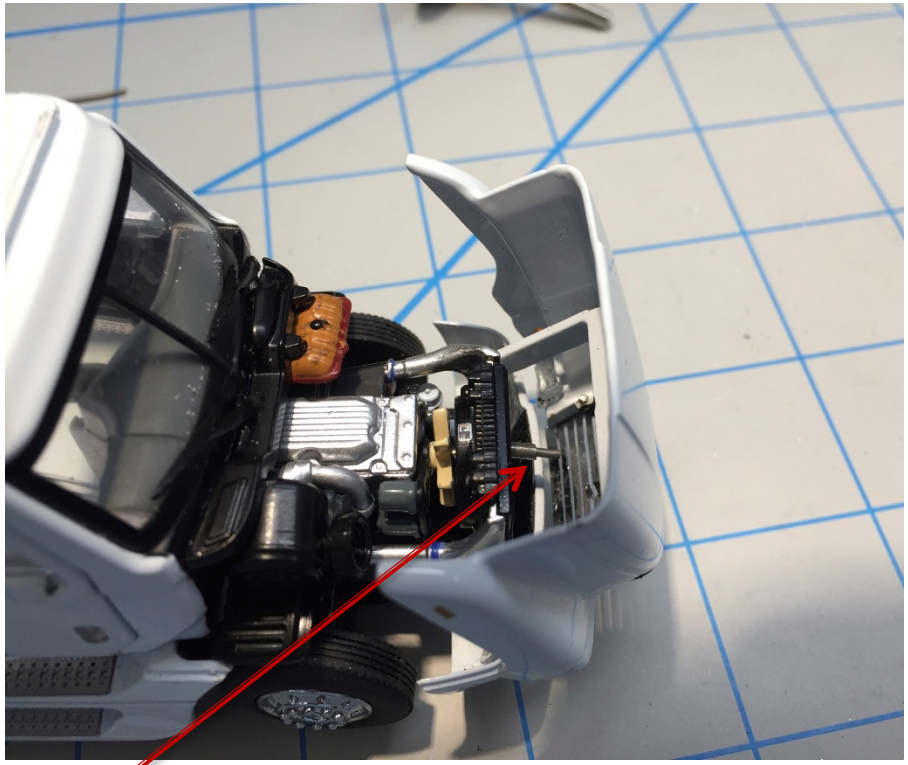
Vehicle platooning: experimental diagnostics

- Body axis force measurements for each vehicle
- Mid-height grille pressure measurements for each vehicle
- Three-component Particle Image Velocimetry (PIV) for flow visualization
  - Single and two vehicle configurations



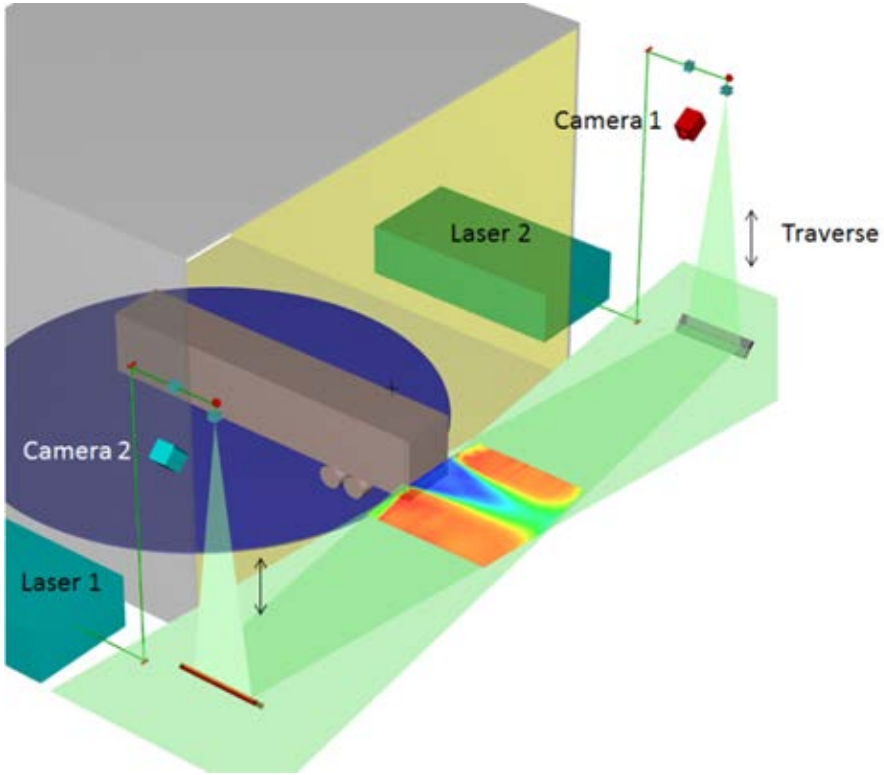
baseline, no boattail, 0° yaw

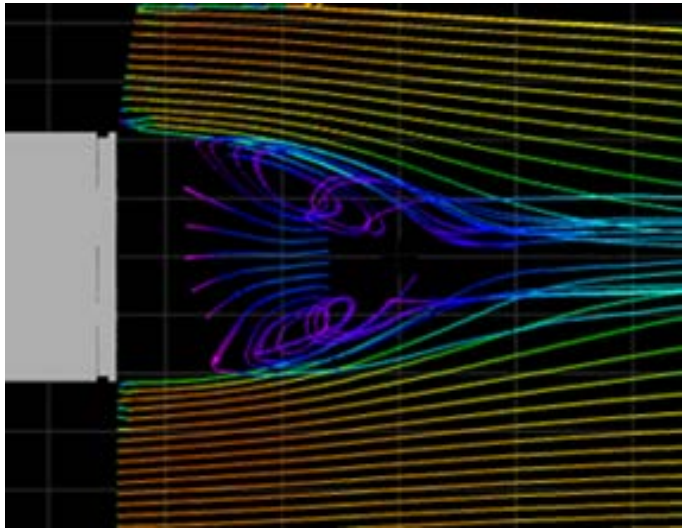
Pressure measurements were obtained at mid-grill height



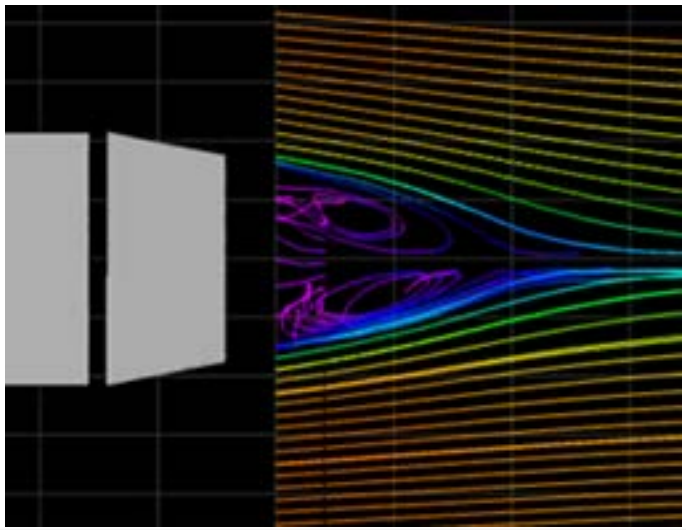
Pressure probe

Three-component Particle Image Velocimetry (PIV) setup at Army 7'x10' wind tunnel



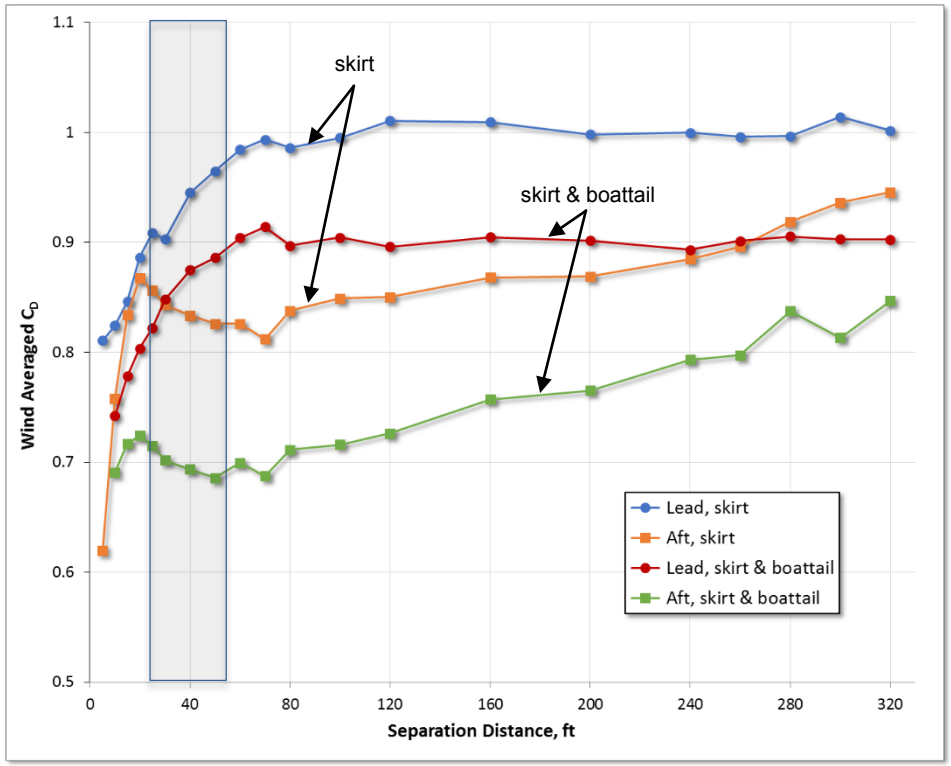


baseline

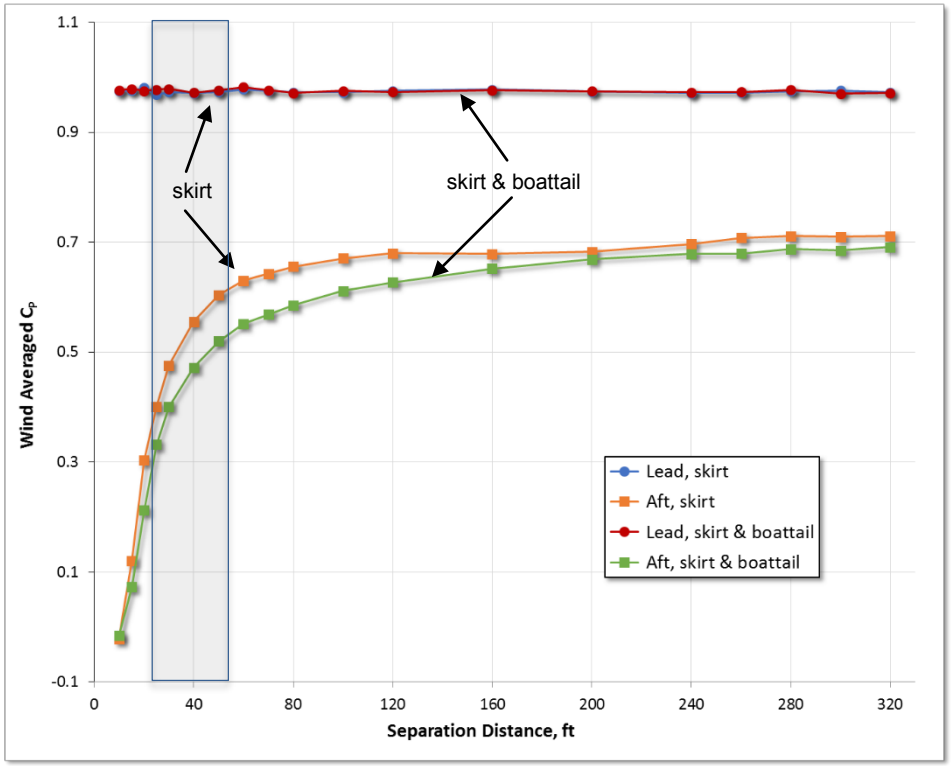


With boattail

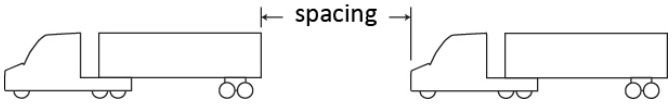
Vehicle platooning: two vehicle configuration, scaled wind tunnel results



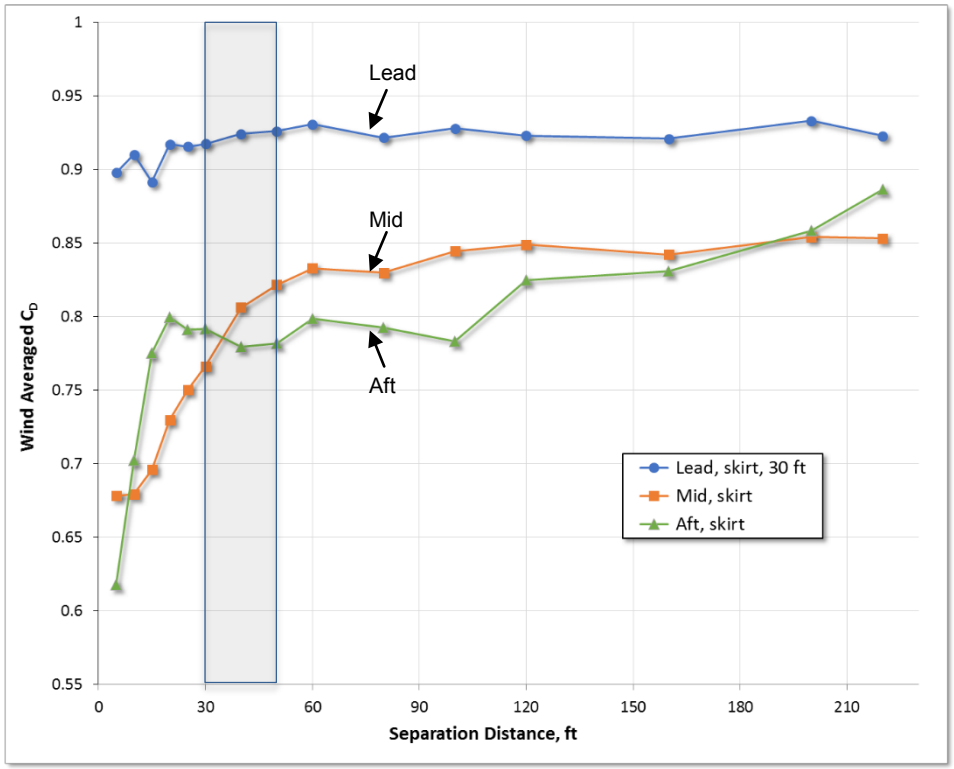
Aerodynamic benefits



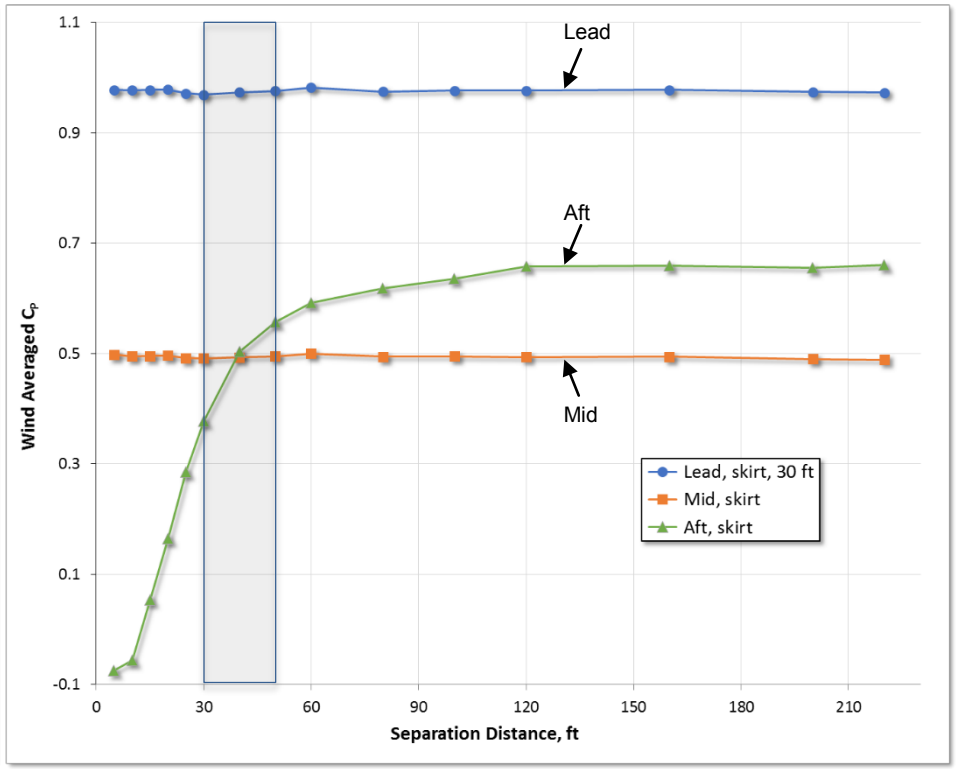
Engine cooling air supply



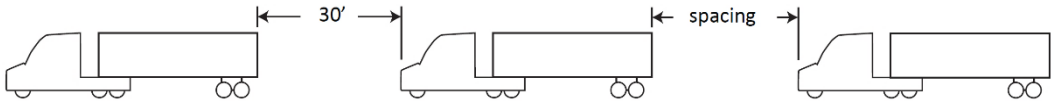
Vehicle platooning: three vehicle configuration, scaled wind tunnel results, 30'



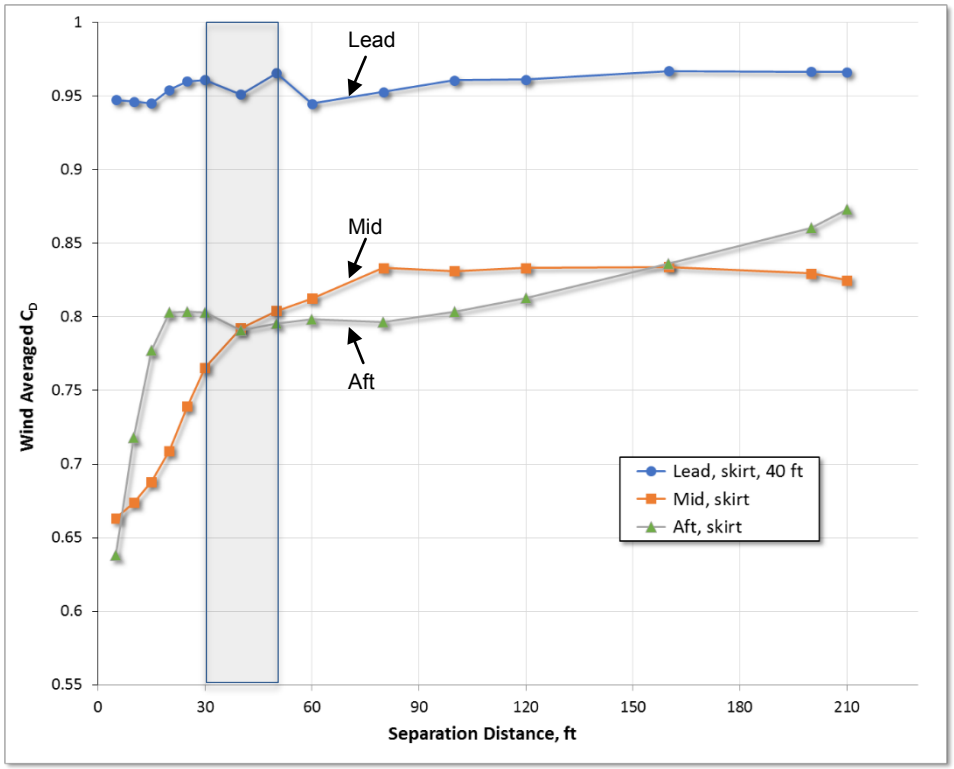
Aerodynamic benefits



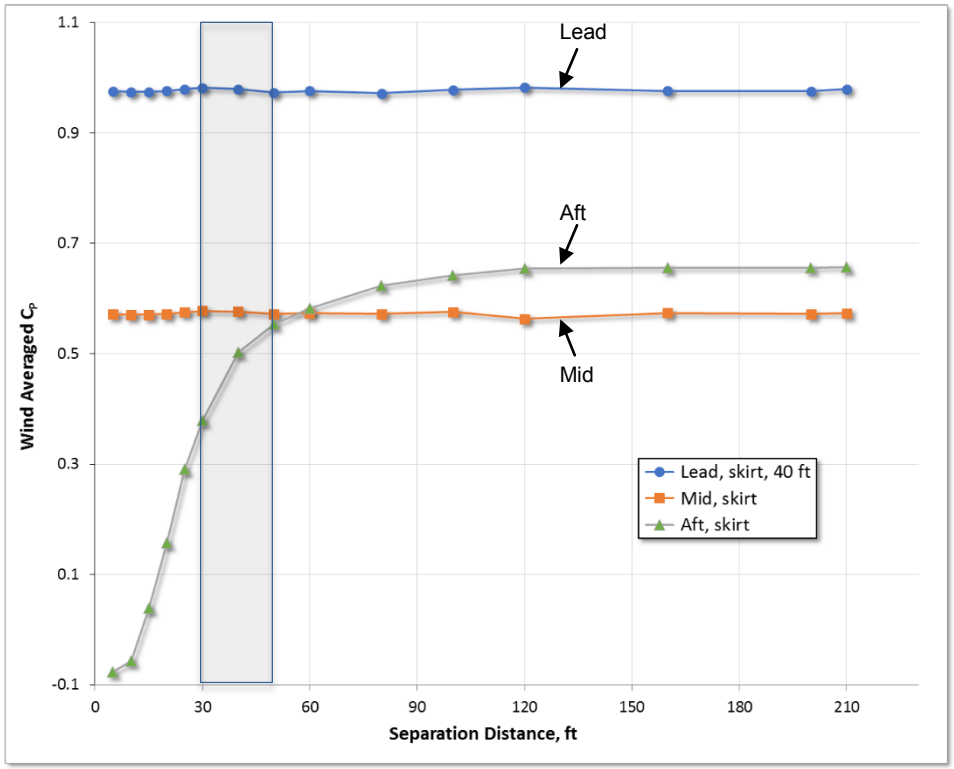
Engine cooling air supply



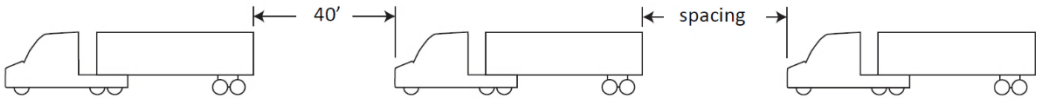
Vehicle platooning: three vehicle configuration, scaled wind tunnel results, 40'



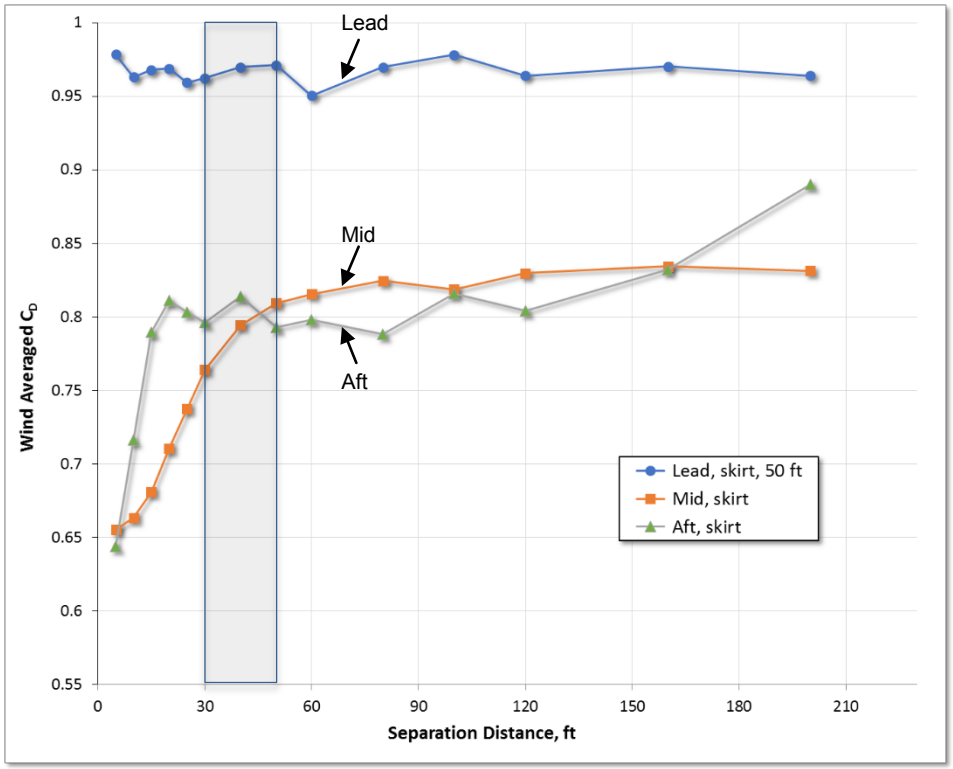
Aerodynamic benefits



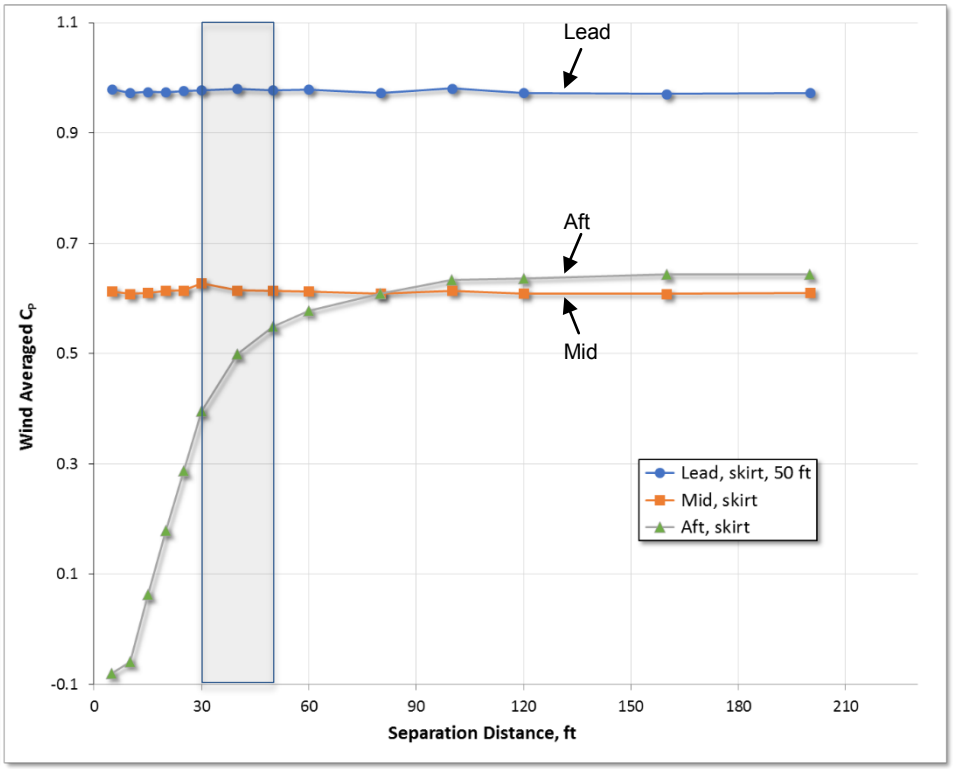
Engine cooling air supply



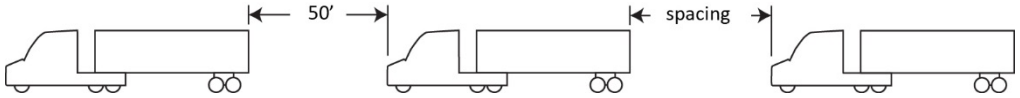
Vehicle platooning: three vehicle configuration, scaled wind tunnel results, 50'



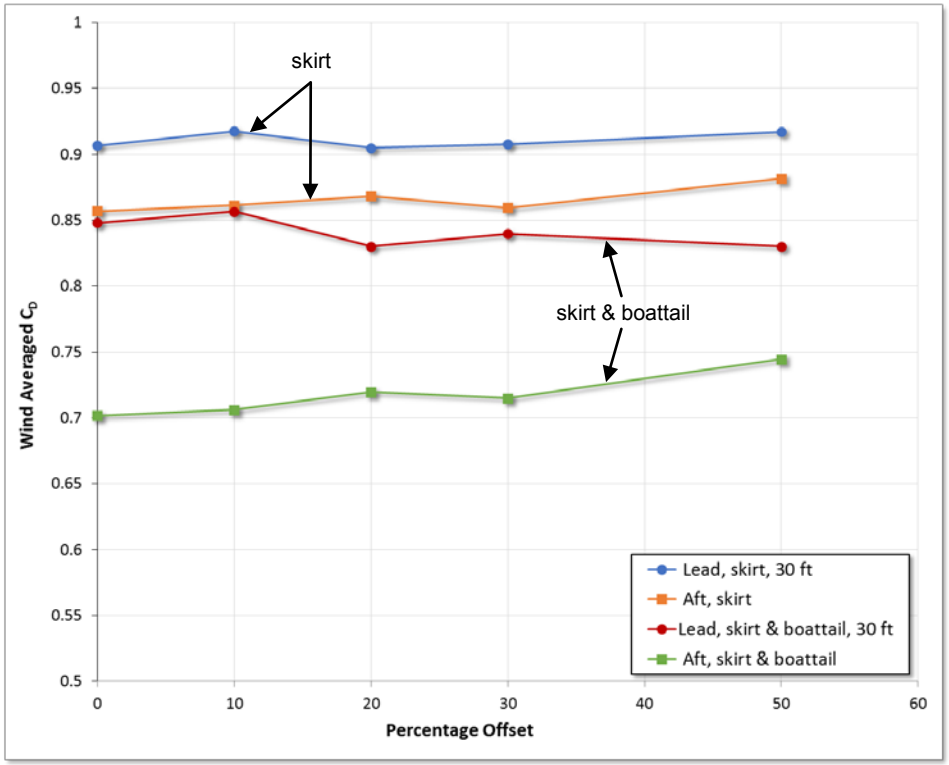
Aerodynamic benefits



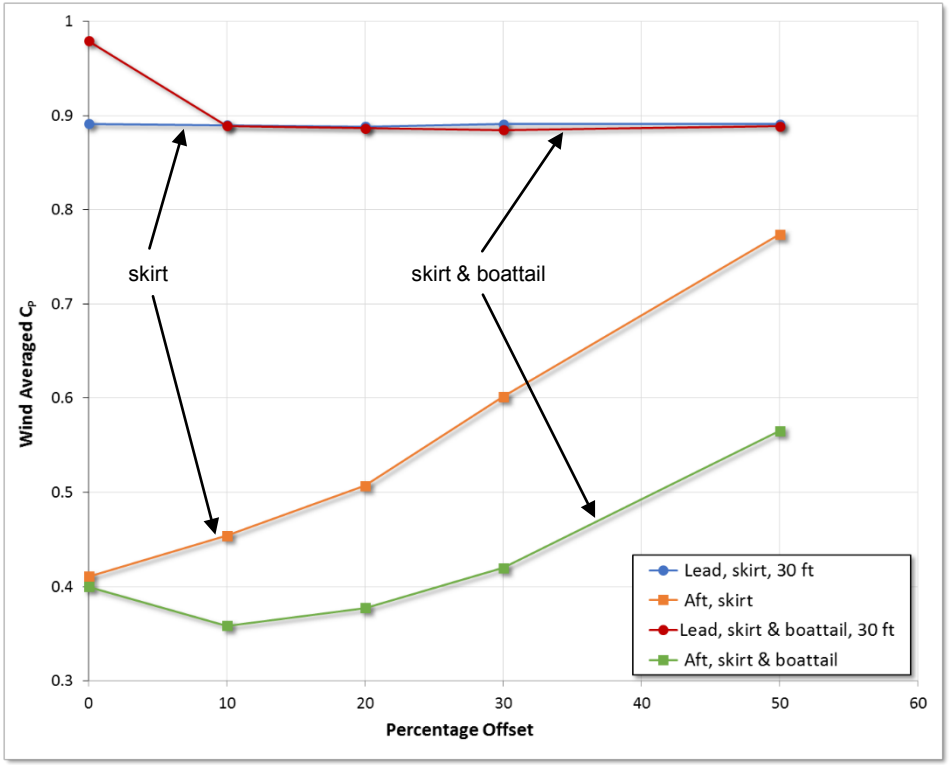
Engine cooling air supply



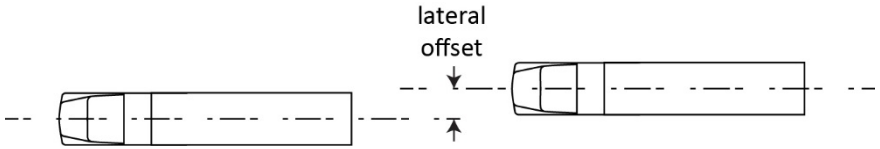
Vehicle platooning: two vehicle misaligned configuration, scaled wind tunnel results, 30'



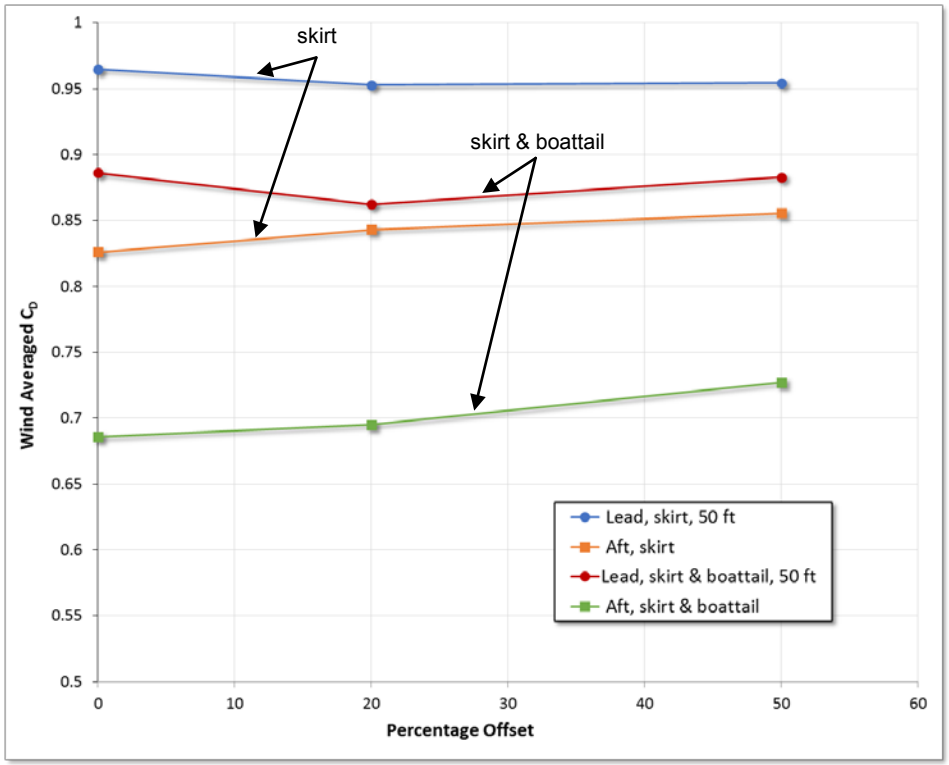
Aerodynamic benefits



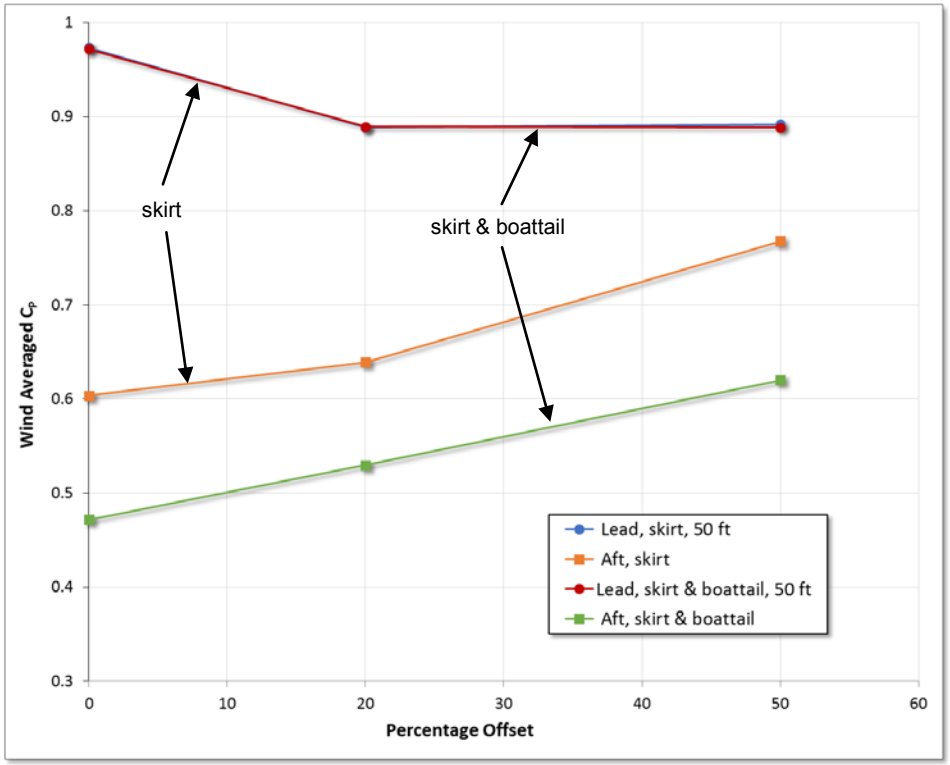
Engine cooling air supply



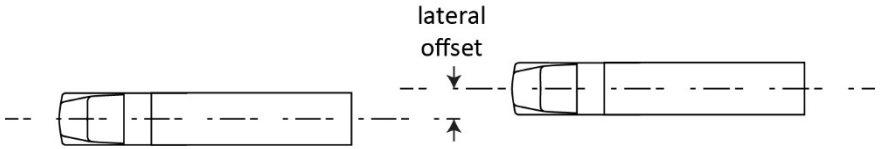
Vehicle platooning: two vehicle misaligned configuration, scaled wind tunnel results, 50'



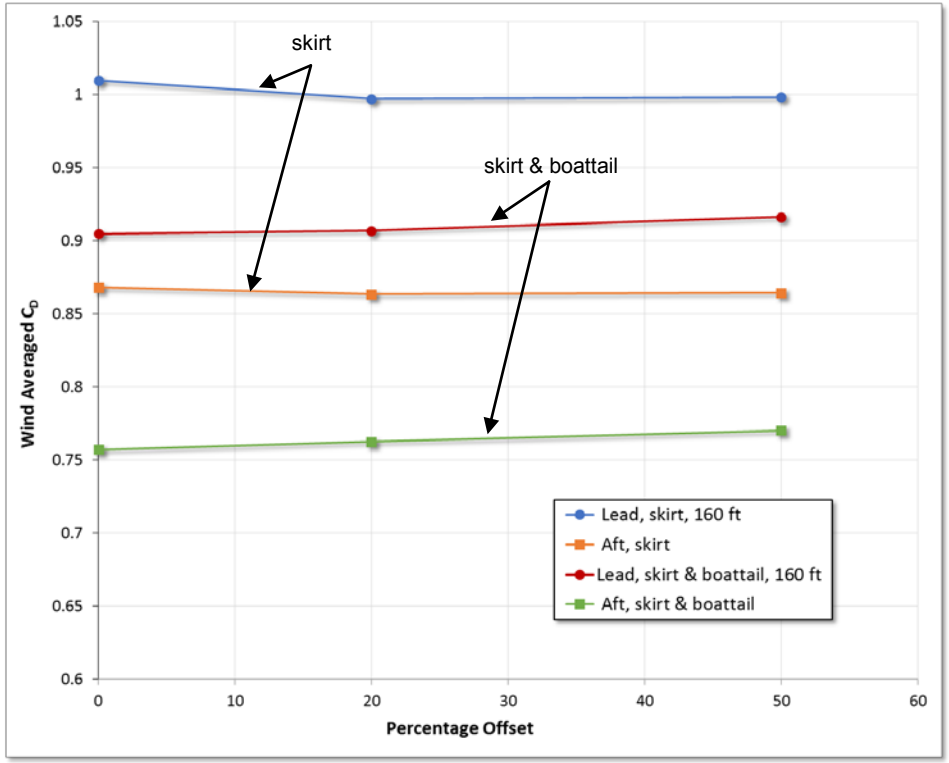
Aerodynamic benefits



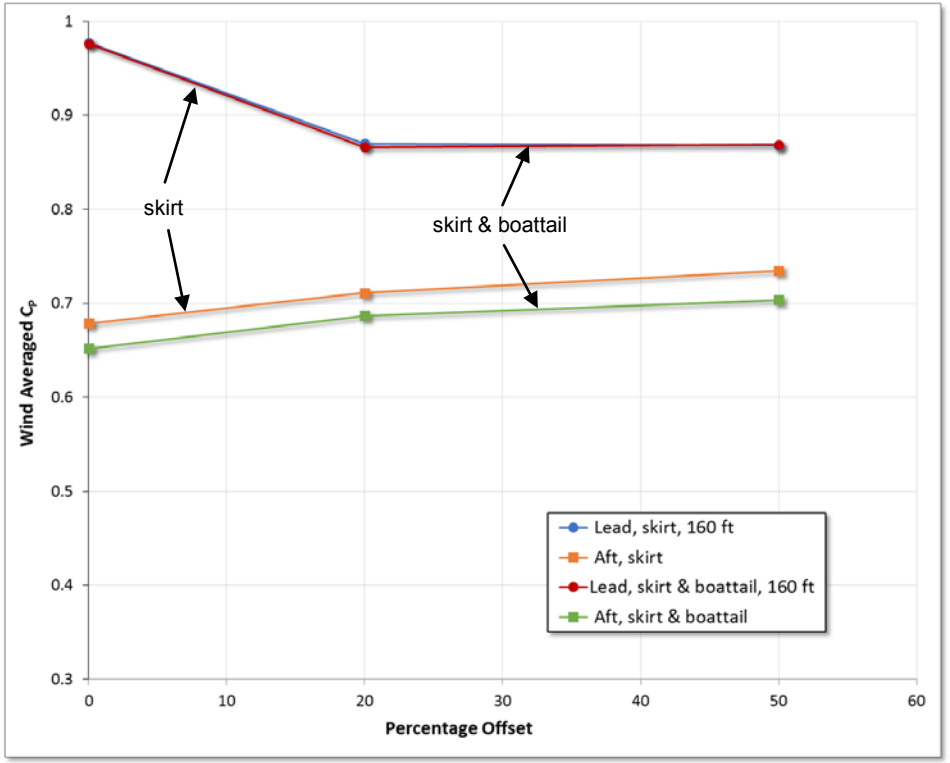
Engine cooling air supply



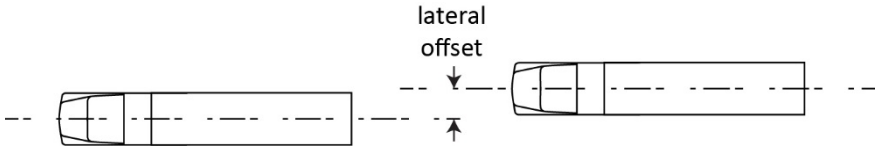
Vehicle platooning: two vehicle misaligned configuration, scaled wind tunnel results, 160'



Aerodynamic benefits



Engine cooling air supply



Responses to Previous Year Reviewers' Comments

Comment: Significant positive feedback from all the reviewers

Response: We thank all the reviewers for their time and effort in reviewing the project.

Comment: The project should do the calculations and simulations (based on published drive cycles)

Response: This is not within the scope of the project, but we rely upon our collaborators (NREL, Navistar, Safeway, Frito-Lay) to provide necessary feedback from their operational testing as it relates to different drive cycles.

Comment: Outright changing shapes without considering things like inter modal transportation (very slow speed, but needs to stack) may be theoretically possible, but would not get DOE to its goals

Response: This project's direction is to provide out-of-the-box aerodynamic technologies for radical drag reduction and fuel economy improvements. We rely upon our collaborators to take these shape concepts and apply the necessary operational constraints to meet their customer's needs. A good example of this approach is Navistar's SuperTruck 1 design.

Collaboration and Coordination with Other Institutions

- Navistar, Inc.
  - Tractor-trailer design
  - Scaled and full-scale wind tunnel testing
- Wabash National and Kentucky Trailer
  - Trailer design
- Freight Wing Inc. and ATDynamics
  - Aerodynamic add-on devices
- Frito-Lay, Spirit, and Safeway
  - On the road testing of aerodynamic devices (multi-year data collection)
- Michelin
  - Lower rolling resistance wide-base single tires
- Praxair
  - Testing our tractor-tanker gap treatment idea
- NREL
  - Full-scale truck platooning track tests
- NASA, Army, and Air Force
  - Wind tunnel testing from small-scale to full-scale

Future plans

- **Continue with the tractor-trailer integration shape design for radical improvement in aerodynamic drag and fuel economy**
- **Continue with the experiments to design the GSF3 integrated tractor-trailer**
- Continue to perform scaled experiments to design and validate the performance of aerodynamic add-on devices for an integrated tractor-trailers and tankers
- **Begin to design the next generation of highly aerodynamic tankers**
- Continue with the investigation of fuel economy benefits of truck platooning in collaboration with NREL
- Continue to work with tanker fleets to improve fuel economy
- On behalf of DOE, continue to coordinate industry participation to design the next generation of highly aerodynamic heavy vehicles

Any proposed future work is subject to change based on funding levels

Summary

- Performed scaled wind tunnel tests to obtain fuel economy benefits of truck platooning
  - single, two, and three vehicle configurations
- Analyzed platooning wind tunnel test results to uncover the underlying physics responsible for the aerodynamic benefits
- Working closely with NREL to conduct full-scale platooning track tests for two vehicle configuration
  - Validate scaled wind tunnel results
- Conducted full-scale wind tunnel tests at NFAC facility in collaboration with Navistar in support of SuperTruck I program
- Investigated the performance of aero devices and integrated design for tractor-trailers and tankers
- Achieved major reduction in aerodynamic drag for tanker trailers through geometry modifications